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15. Supplementary Notes

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16. Abstract (MAXIMUM 200 WORDS)

This report describes an analysis of crew workload and fatigue on Coast Guard cutters. Descriptive measures were obtained on five cutters of three types under normal operations. Evidence of mild fatigue, specifically daytime sleepiness and a degradation of vigilance performance, was observed in many crew members. This study documented levels of workload, performance, and fatigue found in normal, daily Coast Guard cutter operations. Principles of industrial chronohygiene were considered in light of the analysis of crew member sleep patterns, circadian rhythms, and watch schedules. This analysis led to recommendations for watch schedule alternatives that may reduce the probability of crew daytime sleepiness and vigilance performance degradation.

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EXECUTIVE SUMMARY

THE PROBLEM

The Coast Guard (CG) faces continuing reductions in operating budgets and personnel, while it is expected to maintain current levels of service and performance across a broad range of missions. A recent CG report developed streamlined alternatives to current crewing practices without changing the core characteristics, capabilities, or attributes of CG cutters (U.S. Coast Guard, 1996). Potential crew reductions pose challenges for mission effectiveness, crew training and qualifications, onboard maintenance, and logistics. Reductions in crew complement pose questions of risk in the areas of crew workload, fatigue, and, ultimately, safety and mission effectiveness. Data were needed as a benchmark for levels of crew fatigue to enable informed judgments to be made about the tradeoffs between cost reduction and risks associated with crew reduction.

THE APPROACH

This report presents the results of a descriptive effort to determine whether present operations aboard USCG cutters may contribute to excessive crew fatigue, thus exposing crew members to unnecessarily high risks of incidents, accidents, injury, and mission failure. The approach included assessments of workload (stress), effort (strain), performance, and fatigue of selected crew members on selected cutters during operational patrols.

BACKGROUND

Many books have been written about the abstract concept, fatigue. In field studies such as this, fatigue is usually defined "operationally" in terms of performance decrements. As discussed in the report, performance decrements are not a fully satisfactory definition of fatigue because performance may not change in a predictable manner in fatigued individuals. For this project, fatigue was viewed as a *covert* result of the costs generated by effort and performance which, in turn, were responses to work demands. Evidence of fatigue was sought in the perceptions of the crew members, in levels of task performance that were diminished below reasonable expectations, and in behaviors associated with sleepiness[1]. We divided fatigue into three categories: acute fatigue, cumulative fatigue and circadian rhythm[2] effects. Acute fatigue is limited to the effects of a single duty period, such as a 9 to 5 work day. Cumulative fatigue occurs when there is inadequate recovery between these duty periods. Thus, cumulative fatigue usually presents a picture of day-to-day changes for the worse.

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[1] Fatigue is more rigorously defined by physiological measures, such as electroencephalography (brain waves) or assays of certain hormones in body fluids. Since it was not feasible to do these kinds of tests on board, we used indirect evidence of fatigue.

[2] sir-kay'dee-an: an oscillation with a period of about one day, 24 h. The daily, 1° C swing in body temperature, with a low before dawn and a peak in the evening, is the most familiar circadian rhythm. However, many hormones and many kinds of performance, physical and mental, also have normal rhythms with the same or different phase relationships to the day-night cycle.

The operational impact of a human circadian rhythm that is not aligned with the day-night cycle is familiar to anyone who has suffered jet lag. One may experience sleepiness, sleeplessness, an inability to sustain attention, perceptions of physical fatigue, and a general malaise. Research on shift workers has shown that work-schedule irregularity commonly contributes to sleep disruption, performance degradation, and circadian rhythm disruption. These factors were assessed in the present study. Ship motion associated with high sea states was also studied for its contribution to sleep disruption and increased physical effort during waking activities.

METHODS

Baseline data on issues related to crew fatigue were collected during portions of six patrols on three types of Coast Guard cutters. There were no pre-determined manipulations of work conditions aboard the cutters. This was an empirical, observational study, without intervention. The investigation focused primarily on three Reliance class (210') medium endurance cutters (WMECs). The baseline analyses on the three WMECs were supplemented by the analysis of one cutter in each of two additional vessel classes, the Bay class (140') ice-breaking tug (WTGB) and the Hamilton class (378') high endurance cutter (WHEC).

Crew member selection for this project was generally initiated by the Executive Officer, assisted by Department Heads, and approved by the Commanding Officer. A typical sample on a cutter was about 20 crew members composed of about 2/3 watchstanders and 1/3 non-watchstanders, and including several officers.

The workload demanded of a crew member was viewed as a stress, to which the crew member would respond with some evidence of strain, or effort. A Crew Member's Daily Log provided information about the crew members' daily cycles of work, rest, and sleep, as well as other information. Metabolic task descriptions allowed rough estimates of the metabolic demand placed upon the crew member by the job. Ship motion was described in terms of swell and wind/wave height and perceptions of the research personnel. Crew members provided ratings of perceived mental and physical workload, motion discomfort, and motivation.

Crew member performance was measured indirectly by presenting and collecting data from computerized tests. The tests required competence in (1) visual search mechanisms, encoding, decoding, and rote recall; (2) visual pattern recognition and spatial memory, related to crew members' abilities to use a pattern-matching approach to system failure diagnosis; (3) vigilance, the ability to remain alert and watchful in a boring environment; (4) visual temporal acuity, the ability to resolve rapid changes in a visual pattern; and (5) fine motor control and speed. The testing systems were located together at one (WTGB) or two (WHEC, WMEC) testing stations on each cutter. The crew members were asked to test at least twice per day.

Circadian rhythm alignment (with the day-night cycle) of body temperature was assessed by self-measurement. Circadian rhythm problems were characterized by a flattening or phase shift in this rhythm. Acute fatigue was measured as pre-post-work and -watch and -sleep changes in perceptions of sleepiness. Evidence for cumulative fatigue was sought by examining changes in sleepiness and performance across days of data collection.

MAIN FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Approximately 10 to 45% of the crew members displayed one or more signs of mild fatigue. A greater proportion of the crew would be expected to suffer from fatigue, and the associated safety risks and decreased mission capability, under conditions such as high tempo operations, significant maintenance requirements, reduced crew levels, and/or sustained high sea states.

Watchstanders averaged about 9.7 hours of work per day while non-watchstanders averaged about 8.3 hours per day, across all patrol days. Industrial investigations have shown that errors tend to increase disproportionately after about 8 hours of work in one day (cf. Miller, 1992). Overall, the work schedule caused many crew members to work 1.4 to 1.75 times as many hours as they would, for example, in a classic 40-hour week.

Generally, the crew members acquired adequate sleep with respect to their self-reported ideal amounts, but the quality of that sleep was questionable for two reasons. First, the crew members tended to split their sleep into more than one period per day. Watchstanders split their sleep more than non-watchstanders and received less sleep. Splitting sleep is known to reduce sleep quality (cf. Mitler et al., 1997). Second, the average vigilance performance of crew members was impaired, suggesting a level of fatigue similar to that of laboratory subjects sleeping only five hours per night for a week.

In terms of overall performance on the computer-based performance tasks, the crew members performed well except in the area of vigilance. Generally, vigilance tests are the most sensitive of computerized tests with respect to the detection of sleepiness and fatigue due to sleep disruption (cf. Mackie, 1977). The impaired vigilance performance of the crew members was of concern. Vigilance is the ability to sustain and focus attention in a boring situation, with the goal of quickly and accurately detecting the occurrence of a rare, unpredictable, important event. Obviously, this capability applies to underway tasks such as the monitoring of radar, radio, engine and other systems and visual scanning by topside lookouts. Delayed or inaccurate detections in these areas can be problematic for cutter operations.

There was other evidence of crew member fatigue. First, their overall, average rating of sleepiness was much closer to the description, “Losing interest in remaining awake” than to the description “wide awake.” Second, the circadian rhythm of body temperature was somewhat suppressed in watchstanders. Third, the crew members reported about the same acute changes in sleepiness across single work and watch periods as office workers. Of course, the watch periods were only half as long as office work days, and the crew members worked more hours per day than office workers. Finally, vigilance performance, pattern matching performance and temporal visual acuity all declined from day to day, though the crew members reported no perceptions of accumulating fatigue. This lack of perception of declining abilities mirrors a similar effect of alcohol.

Among all of these observations, the effect of greatest concern for cutter operations is the somewhat degraded vigilance performance of the crew members. Likely causes for this impairment were:

- average number of hours worked per day
- average number of hours of sleep per day
- average number of sleep periods per day
- circadian rhythm suppression
- daily changes in temporal visual acuity
- age (youth)

The interrelationships among these measures and the vigilance measures were examined and the following findings emerged:

Age had a stronger association with crew member vigilance performance than any other factor we examined. Interestingly, greater age was associated with better vigilance performance. This may reflect a somewhat higher level of discipline for paying attention in the older crew members. The total age range of the crew members tested was from 22 to 40 years.

The number of hours of sleep acquired each day was second only to age in its association with vigilance performance. As expected, more sleep was associated with better vigilance performance, greater lapse response speed, and fewer lapses. The total number of hours of work and watch each day was ranked third in its association with vigilance performance. As expected, more work was associated with poorer vigilance performance.

These results suggest that crew members should be given education and training about the impact of reduced sleep on their vigilance performance so that they will realize the need to manage their sleep times and to obtain recovery sleep when needed. In addition, the formal creation of non-traditional periods (such as afternoon naps) for recovery sleep is recommended.

Watchstanders slept less, and split their sleep more, than non-watchstanders. It was clear that the standing of watches had some degree of influence upon the amount of sleep acquired and the number of periods needed to obtain that sleep. As a result of this association, we explored some possibilities for improved watch scheduling. The recommendations were based upon known principles of chronohygiene (Hildebrandt, 1976), namely, giving 24 h of recovery between night work periods and keeping the human circadian rhythm aligned with the day-night cycle. The use of watch rotations that comply with the principles of chronohygiene, would ease the stress and strain experienced by watchstanders.

Crews also should consider an alternative to the observed practice of using late sleeping for night watchstanders and encouraging late sleeping on Sundays by not piping reveille.

A constant waking time from day to day is a very strong time cue that helps align the body's rhythm to the day-night cycle. Synchronization (alignment) of the body's rhythm to the day-night cycle helps prevent the general feeling of malaise and other jet-lag-like symptoms, including an increased risk of errors.

It would also be appropriate for crews to establish a mid-afternoon *siesta* period for night workers and to encourage the *siesta* on holidays instead of late sleeping. The *siesta* would be in accordance with the daily biological pattern of human sleepiness and error probability (Mitler and Miller, 1996; Folkard, 1995).

Even though our data were collected during relatively low tempo operations, these crews exhibited signs of fatigue, including reduced levels of vigilance. High tempo operations would be expected to exacerbate these problems, since work-rest schedules would likely be altered, and total sleep achieved would probably be reduced. In order for Coast Guard crews to be *Semper Paratus*, it is recommended that additional studies be undertaken to develop and implement a crew endurance management program for the Coast Guard (see, for example, Comperatore, 1997). Such a program would take a broader look at cutter activities and consider not only individual work-rest schedules, but also drill and training schedules, and sleeping accommodations to determine what types of changes might be made that would improve crew member sleep duration and quality without sacrificing mission requirements. The crew endurance management program would also include training for the crew and commanding officers in order to make crew alertness or "readiness" a part of Coast Guard culture.

This study established baseline levels of workload, performance, and fatigue found in normal, daily Coast Guard cutter operations. Mild fatigue was found in 10-45% of the crew members tested, despite the fact that no high tempo operations were observed. The baseline measures were quantified and are presented as means and standard deviations in appendices to this report. There were recommendations for changes in watch scheduling and for the structures of subsequent studies, but the data from this study cannot be used to make or support any recommendations about the tradeoffs between cost reduction and risks associated with crew reduction.